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MODIFIED COST ESTIMATING MODEL FOR 20MM-40MM AUTOMATIC CANNON AMMUNITION INITIAL PRODUCTION FACILITIES

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TECHNICAL REPORT

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ABSTRACT

A model to provide cost estimates of initial production facilities (IPF) for a 20mm through 40mm steel-case or aluminum-case family of conventional automatic cannon ammunition is presented in this report. The model is intended to facilitate the preparation of independent estimates in support of decision making early in the acquisition phase. It represents a modified version of previous models over the same size range developed by HQ, ARMCOM, Cost Analysis Division, in that different costs among alternative rounds of different calibers and/or component dimensions are generated. The differentiating or adjusting process is based on the premise that production equipment capacities are partially or wholly dependent on the magnitude of certain component dimensions that are known or can be assumed in early estimates.

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SECTION I

INTRODUCTION

A. Background

In April, 1975, HQ, ARMCOM Cost Analysis Division initiated a long-term study to develop investment cost estimating tools for ammunition to facilitate independent cost estimates. The initial volume, covering medium-bore (20mm through 60mm) automatic cannon ammunition, was published in September, 1975 and is shown as reference 1. The initial study results include two models for estimating the cost of initial production facilities (IPF) for conventional medium-bore ammunition. The first model covers ammunition in sizes from 20mm through 30mm, and is based on IPF data used for the Vehicle Rapid Fire Weapon System Independent Parametric Cost Estimate (IPCE) alternatives published in August, 1974. The second model, covering ammunition over 30mm through 60mm, is based on a 57mm recoilless rifle round and utilizes dimensional adjustments to scale estimated costs over its intended range.

Subsequent application of the IPF cost models in the preparation of early alternative ammunition cost estimates in the 20mm through 40mm size range for the Army Radar Gun Air Defense System (ARGADS) Project Manager Office revealed abnormal breaks in estimated cost at the interface of the two models. This problem indicated that the production methods on which the over 30mm model are based are not compatible, from a processing or production rate standpoint, or both, with automatic cannon ammunition down to 30mm and very likely to 40mm. In addition, the 20mm through 30mm model was developed to yield a single estimated cost owing to the narrow range of application. Both of the foregoing conditions rendered use of the existing models unsuitable for comparison of the alternative ARGADS rounds. Therefore, the existing model was modified as described in this report.

B. Purpose

The purpose of this report is to present a modified model suitable for estimating the IPF cost of alternative families of conventional medium-bore automatic cannon ammunition in calibers from 20mm through 40mm. Specifically, the modified model will provide different estimates for rounds of different calibers and/or component dimensions which, under the assumptions of the model, act to drive IPF costs. The model represents a refined version of the initial model, and is an interim approach to continuing refinement of such models. The modified model is completely described; however, the information in reference 1, pages 6,7, and 94, relating to the mobilization plan and special findings also apply to this report.

C. Scope of Model

The cost elements for which cost equations are provided in the model are shown in Table 1. The IPF outputs include allowances for IPE transportation; installation; layaway; and, for LAP, miscellaneous material handling equipment. Since the government may not buy capital equipment for a given ammunition program, but will incur costs for special tooling and gages that are unique to the ammunition being procured, the model is structured to provide separate estimates of initial tooling and IPE.

The model excludes certain costs which may be incurred but remain for the individual estimator to resolve as required. These are as follows:

1. Non-IPF/Initial Tooling

This element includes the costs of real property construction (buildings, utility systems, installed building equipment, etc.), real estate acquisition and/or improvements, and other production base support activities under the cognizance of the Corps of Engineers; and non-production equipment such as office machines and equipment. Therefore, the model is confined to IPF as defined in Chapter 4, Section III, of reference 2.

2. Propellants and Explosives (P&E) IPF

The IPF portion of the Army's industrial production base is established, maintained, modernized, and expanded on the basis of component demand. The completed round is important only to the extent that it contributes, along with other total rounds, to the demand for the particular components. For example, the Army does not provide TNT capacity for a specific HE projectile; rather, capacity is based upon total TNT demand. This is a different situation than IPF for metal parts production and complete-round LAP, where discrete production bases are required in support of components for a specific family of rounds. The consequence of this special consideration is that the estimator must make certain that the IPE involved reflects the marginal increase in capacities and does not duplicate available, uncommitted capacities. Owing to this marginality, the various P&E items and combinations thereof, and the multitude of planned modernization and expansion projects, the P&E area has been excluded from the model.

3. Material Handling Equipment/Control Systems

The specific plant layout, and the production rate, quantity, and physical bulk of the ammunition components being produced have, singly or in combination, a significant impact on the selection of this type of equipment. The equipment could vary from very simple (almost none) to very special (approaching fully automated handling). A general-purpose model intended to be applicable early in the system life cycle over a potentially wide range of the foregoing conditions, would require a series of subroutines to reflect varying degrees of equipment/control system automation. These have not been developed, but are under consideration for future phases of the reference 1 study. However, an allowance for miscellaneous material handling equipment is included in the Load, Assemble, and Pack (LAP) IPF model.

Table 1. IPF Cost Elements

1. Industrial Plant Equipment (IPE)

   a. Projectile (HE, AP, and TP)

   b. Link

   c. Box

   d. LAP

   e. Steel Cartridge Case

   f. Aluminum Cartridge Case

   g. Fuze

2. Initial Tooling

   a. Projectile (HE, AP, and TP)

   b. Link

   c. Box

   d. LAP

   e. Steel Cartridge Case

   f. Aluminum Cartridge Case

3. Test and Measuring Equipment (TME)

   a. Projectile (HE, AP, and TP)

   b. Link

   c. Box

   d. LAP

   e. Steel Cartridge Case

   f. Aluminum Cartridge Case

   g. Fuze

D. Assumptions and Constraints

1. Although the model will execute for any assumed production rate, no upper and lower limits being established, the data base reflects full-rate production methods. In application of the model, IPF can be established to meet mobilization rate requirements, and assumed to be utilized at a lower, full scale production (FSP) rate to produce the Authorized Acquisition Objective (AAO), or war reserve, for the program being estimated. For very high production rates, it is recommended that the estimator verify the adequacy of the production methods reflected in the model with appropriate ammunition production base personnel.

2. The model assumes the acquisition of all new production equipment for each component for which production rate inputs are provided. Modifications to account for existing capacity or available production equipment must be handled outside of the model.

3. The model generates a parametric estimate driven by known or assumed component overall dimensions, and does not reflect the impact of discrete design detail. The basis of the model is the 25mm Philco-Ford family of Bushmaster ammunition (GAU-8 for the aluminum cartridge case).

4. The model contains no stated upper or lower limits for dimensions other than caliber. However, practical considerations of production methods and equipment requirements will constrain useful application of the model to ammunition that is appropriate for 20mm - 40mm automatic cannon use. Examples of rounds over this range which have been estimated using the model are:

Round	Projectile Length	Case Length	Assumed No. of Rounds Per Box
M246 20mm	3.025	4.015	100
Oerlikon KBA 25mm	4.3	5.5	50
GAU-8 30mm	5.49	6.81	50
Oerlikon KDA 35mm	7.4	5.1	25
Bofors L/70 40mm	8.13	14.37	15

5. Although the model is based on established processes and equipment currently available on the market, it is not intended to represent any facility either proposed or currently in operation. However, the manufacturing processes shown are similar to equivalent processes described in references 3 through 6.

6. The model is intended to provide IPF estimates in support of decision making early in the acquisition phase. It is not intended to be used for budget/program estimates or for production planning purposes.

7. Because of the complexity of the model, its supporting data base, and the level of detail at which cost estimates are generated, it is intended that the model be exercised by computer. The model is currently

programmed on the WANG 700 Series programmable calculator located in the HQ, ARMCOM Cost Analysis Division, and will be included as part of the IBM 360/65 automatic cannon cost model program currently under development.

8. The model makes no provision for standby production equipment to preclude line shutdown in the event of equipment breakdown. In addition, no allowance is made in the working-shift hours for preventive maintenance.

9. All costs are in FY 1975 constant dollars.

SECTION II

MODELING APPROACH

A. General Approach to Modification

The modified model utilizes the 20mm through 30mm model of reference 1, and the aluminum-case model derived from reference 5, as a base. The general approach to modification of the base model consisted of the following:

1. Establishment of 40mm as the model upper limit.

Extension of the production processes/equipment over an additional 10mm, in combination with the dimensional adjustments described herein, was verified as a technically valid approach for estimating purposes by discussion with Lake City Army Ammunition Plant (LCAAP), Ammunition Technology Division. This modification was considered necessary both to provide differential cost estimates without unexplainable cost breaks over the range of calibers expected in application of the model to typical gun-ammunition studies, and to provide a full-range submodel as part of the automatic cannon cost model.

2. Selective modeling of dimensional adjustments.

Adjustments are made both to individual production equipment capacities (or, what is the same thing, adjustments are made to establish an "effective" production-rate input), based on differing component dimensions; and, for cartridge cases, to compute varying numbers of press drawing and related processes over predetermined ranges of case length. The approach to equipment-capacity adjustment is based solely on the premise that process cycle times, and hence production-rate capabilities, for the majority of processes are partially or wholly dependent on the magnitude of certain component dimensions. In the extreme case where engineering estimates can be made on the basis of production drawings, both types of adjustment will indirectly result from differences in discrete design detail. However, for early estimates for which overall dimensions are the best that can be defined, adjustments based on those dimensions are necessary. The end result is a parametric estimate which differentiates, on the basis of engineering judgment, among departures from a defined data base representing known dimensions, and in which the adjustments move costs as definitively as possible in the proper direction. These types of judgmental adjustment can then be refined over time by lower-level investigation and analysis. It is important to note in the model of dimensional adjustments that when the base (reference 1) model dimensions (numerical constants in the adjusting terms of the equations) are input to the model, the outputs are identical to that provided by the base model itself, with the exception of modifications 3 and 4, below.

3. Revision of the steel cartridge case equipment data.

These changes were based on the steel case line of reference 3, and included the addition of a disc grinding operation and revision of the material-treatment processes associated with the press drawing operations.

4. Adjustment of initial tooling cost by caliber.

This adjustment follows the approach used by LCAAP for the Bushmaster IPCE, and are applied as an estimator of the generally higher tooling cost expected with increases in caliber.

In addition to the foregoing modifications to the base model, an aluminum cartridge case model, based on an estimate prepared in support of the continuing reference 1 study effort, has been added.

B. Methodology and Data Sources

1. Base Model

The IPE (machine tools and processing equipment) required for the manufacture of a 20mm through 40mm steel-case or aluminum-case ammunition family, excluding fuzes, is shown in Tables 2 through 9. The equipment lists in Tables 2 through 8 were synthesized for the reference 7 study by analyzing the manufacturing processes necessary to produce 20mm through 30mm ammunition. An adjustment factor of 1.25 was used to inflate equipment unit costs from FY 73 dollars to FY 75 dollars. The inflation factor was developed from a detailed review of the production base support (PBS) Procurement Requisition Order Numbers (PRONS) for FY 74 on ARMCOM projects. The price changes on the PRONS indicated a change of 12 percent through the fiscal year. ARMCOM PBS specialists projected the same rate of change between FY 74 and FY 75. The two-year factor then becomes (1.12)(1.12)=1.25. The equipment list in Table 9 was derived from the aluminum-case IPF estimate in reference 5, in which all costs are provided in FY 75 dollars. All lists were then modified as described in paragraph IIA.

The initial tooling required by the IPE of Tables 2 through 8 was developed by analyzing the manufacturing processes and equipment requirements. The estimated costs shown in the tables were inflated from FY 73 dollars to FY 75 dollars using indices from references 8 and 9. The initial tooling costs in Table 9 were taken from reference 5.

Estimates of TME costs in FY 75 dollars were developed from an analysis of requirements and costs for ammunition over 30mm conducted for the reference 1 study.

Fuze line data was provided by Frankford Arsenal, Manufacturing Technology Directorate, Mobilization Engineering Division (SARFA-MTE). Line capacity and cost, including the cost of initial tooling, is based on the XM714 fuze line. The XM714 fuze is planned for use on the 20mm M50 series, Bushmaster 25mm, and GAU-8 30mm families of ammunition. Although use of this fuze for rounds over 30mm in size is improbable, it is assumed that a fuze of this type will be used. SARFA-MTE concurs that the XM714 fuze line capacity and cost is applicable over the 20mm through 40mm range.

In addition to the equipment and initial tooling costs obtained from Tables 2 through 9 for each component and LAP, the cost model selectively includes allowances, in the form of percentages of equipment cost, for transportation, installation, layaway, and miscellaneous material handling equipment; and thruput costs for TME (see paragraph IIIC). The transportation and installation allowances were provided by the US Army Production Equipment Agency Engineering Division (DRXPE-EN), and represents an average based on an equipment mix ranging from lathes to 500 ton presses. The allowance for layaway cost was provided by the HQ, ARMCOM Procurement and Production Directorate, Industrial Management Division (DRSAR-PPI-W).

The cost model consists of a series of cost equations and a supporting data base. When solved using specific inputs provided by the estimator, the equations yield estimates of total IPE, initial tooling, and TME for each of the components of Table 1. Tables 2 through 9 constitute the data base for all of the cost elements except fuzes, and are structured in the form of matrices from which the model selects the equipment and cost values required for solution of the cost equations. In the solution of the equations, the estimating model performs the following:

a. The number of machines required is calculated based upon:

(1) annual production requirements (inputs to the model).
(2) the assumed number of shifts (inputs to the model).
(3) equipment item capacity per shift per year (included in the data base).
(4) the number of rounds per metallic ammunition box when boxes are necessary (input to the model).
(5) for affected equipment items, relevant component dimensions (inputs to the model).

b. The estimated total cost of each item of equipment is calculated using the results of a, above, and the equipment item unit cost (data base).

c. The estimated total cost of all equipment required to produce each component and to LAP complete rounds is calculated by summing appropriate costs yielded in b, above.

d. The number of sets of initial tooling required for each equipment item is calculated using the procedure of a, above.

e. The estimated cost of initial tooling is calculated using the procedure of b and c, above, but based on the results of d, above, and the average unit tooling cost (data base).

Fuze IPE and initial tooling cost is provided at a summary level, i.e., total line including transportation, installation, and initial tooling, and requires a single solution of the cost equations. For this reason, no matrix is provided for fuzes, nor is fuze initial tooling separately calculated. TME costs are provided as summary-level thruputs; hence, no calculations are required.

2. Dimensional Adjustments

The machine-process listings of the revised base model were analyzed in detail to determine which overall component dimensions, if different than those of the base model, will impact the production capacities of the individual equipment items. The magnitude of the impacts were then individually assessed and expressed as percentages of change to the basic quantity-of-equipment equations of the reference 1 model. These were translated into modified equations to yield adjusted quantities of equipment required to meet the production rate inputs to the model. Both judgmental assessments were primarily based on review of the detailed manufacturing descriptions of references 3 through 6. Adjustments to alter the number of press drawing, and indirectly the number of associated processes, are based on information obtained by HQ, ARMCOM Plant Operations Directorate.

The dimensional adjustments and resulting equations are described in additional detail in paragraph IIIC2.

TABLE 2 HEIT PROJECTILE (k=1) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14)	(j=15-∞)
1	1	Auto Screw Machine	$87.570	.383	4.88	4.880	4.880	4.880	4.880	3.256	3.256	3.256	2.713	2.713	2.713	2.646	→
2	2	Secondary Open Chucker	73.670	1.133	2.44	1.832	1.628	1.628	1.465	→							
3	3	Centerless Grinders	40.310	1.700	0	→											
4	4	35-Ton Hydraulic Press	16.680	1.700	2.44	1.832	→										
4	5	4-Ton Hydraulic Press	8.340	1.700	0.61	0.488	0.488	0.427	→								
4	6	Press, Band Swaging	6.950	2.300	4.88	3.663	→										
3	7	Phosphate Coating Unit	63.940	2.300	0	→											
3	8	Magnetic Inspect Mach	37.530	2.300	0	→											
3	9	Wash, Rinse & Dry Unit	25.020	2.300	0	→											
2	10	Marking Machine	3.475	2.300	0	→											
3	11	Painting Machine	48.650	4.600	0	→											

TABLE 3 APT PROJECTILE (k=2) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→∞)
1	1	Auto Screw Machine	$87.570	.413	8.55	8.550	5.291	4.880	4.880	4.477	→
2	2	Single Spindle Screw Machine	25.020	.825	4.88	3.663	3.256	→			
3	3	Centerless Grinders	40.310	2.250	0	→					
4	4	Tocco Indus Heat Unit	48.650	2.250	0	→					
2	5	Turret Lathe	31.970	1.125	1.22	.916	→				
4	6	Press, 15 Ton	8.340	1.125	2.44	1.832	→				
3	7	Degreaser	25.020	2.250	0	→					
3	8	Magnetic Part Insp Machine	37.530	2.250	0	→					
3	9	Phosphate Coating Unit	79.230	2.250	0	→					
3	10	Painting Machine	48.650	2.250	0	→					

TABLE 4 TPT PROJECTILE (k=3) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→∞)
1	1	Auto Screw Machine	$87.570	.542	4.88	3.663	3.663	3.663	3.663	2.849	→
2	2	Auto Screw Machine	73.670	.650	4.40	2.686	2.686	2.686	1.661	→	
3	3	Centerless Grinders	40.310	1.625	0 →						
4	4	Hydraulic Press (35 Ton)	16.680	1.625	2.44	1.832 →					
4	5	Press, Band Swaging	6.950	1.625	4.88	3.663 →					
3	6	Phosphate Coating Unit	79.230	1.625	0 →						
3	7	Magnetic Part Insp Machine	37.530	3.250	0 →						
3	8	Wash, Rinse & Dry Unit	25.020	3.250	0 →						
2	9	Marking Machine	3.475	3.250	0 →						
3	10	Painting Machine	31.970	3.250	0 →						

TABLE 5 LINK (k=4) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7→∞)
5	1	150-Ton Blank & Form Press	$127.880	4.025	134.31	106.838	93.611 →		
5	2	#35 Mult. Slide Press	95.910	4.025	48.84	39.683	36.630 →		
5	3	Secondary Opr. OBI Press	31.970	2.683	18.32	18.320	14.245	13.736 →	
5	4	Heat Treat Furnace	166.800	8.050	0 →				
5	5	Vibratory Deburring Machines	79.230	4.025	0 →				
5	6	Assembly Machine	23.630	4.025	0 →				
5	7	Ranschoff Wash & Dry	31.970	4.025	0 →				
5	8	Vapor Degreaser	16.680	4.025	0 →				
5	9	Phosphate Coating Sys.	95.910	8.050	0 →				

TABLE 6 BOX (k=5) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10 → ∞)
6	1	Punch Press 135-150 Ton	$31.970	6.7	67.16	67.160	67.160	57.998	57.387	56.980	→	
6	2	Punch Press 60-70 Ton	16.680	6.2	9.77	9.770	9.770	9.310	9.280	9.259	9.244	→
6	3	Punch Press 20-30 Ton	8.340	8.3	4.88	4.880	4.477	4.426	4.396	→		
6	4	Press Brake 50-60 Ton	16.680	8.3	9.77	9.770	9.361	9.310	9.280	→		
6	5	Seam Welders	19.460	5.0	0 →							
6	6	Spot Welders	12.510	2.8	0 →							

NOTE: $X_{i,2,k}$ (the production equipment capacity for ammunition boxes) is expressed in rounds of ammunition instead of boxes, i.e., 67,000 boxes times 100 rounds/box = 6,700,000 rounds.

TABLE 7 LAP (k=6) (FY 75$)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14 → ∞)
5	1	Blending Units	$ 11.120	4.200	0 →											
5	2	Pelletizers	23.630	4.200	6.11	4.880	→									
7	3	Charging Machine	214.060	1.680	18.32	18.320	18.320	18.320	11.477	→						
8	4	Straight Line Loaders	87.570	1.680	9.77	9.770	9.770	9.770	4.880	→						
9	5	Auto Fuze Assemblers	48.650	.764	1.22	1.220	1.220	1.220	1.220	1.220	1.220	1.220	1.220	1.220	.333	→
5	6	Gage & Weight	87.570	4.200	14.65	12.210	→									
9	7	Can Sealer	11.120	2.800	0 →											
5	8	Marking Machine	16.680	4.200	0 →											

TABLE 8 STEEL CARTRIDGE CASE (k=7) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Operation	Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Equipment Unit Cost In Thousands (j=3)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12→∞)
5	1	Blank	100T(j=1)/200T(j=2)	$ 69.500	5.050	$ 139.000	12.21	7.570							
3	2	Grind	Auto Disc Grinder	54.000	10.160	54.000	0.50								
10	3	Preanneal Wash	Multistage Washer	10.000	4.870 1/	10.000	0								
10	4	Anneal	Annealing Furnace	150.000	4.970 1/	150.000	0								
10	5	Phosphate Lube& Dry	Multistage Phosphating Unit	200.000	5.720 1/	200.000	0								
5	6	Coin Cup	400T	278.000	3.367	278.000	2.93	2.320	2.116						
5	7	1st Draw	150T(j=1)/200T(j=2)	104.250	3.367	139.000	0.98	.794	.733						
5	8	2d Draw	100T(j=1)/200T(j=2)	69.500	3.367	139.000	0.98	.794	.733						
2	9	2d Draw Trim	Rotary	22.240	2.020	22.240	0.61	.610	.448	.427	.415				
5	10	3d Draw	100T(j=1)/200T(j=2)	69.500	3.367	139.000	0.98	.794	.733						
2	11	3d Draw Trim	Rotary	23.630	2.020	23.630	0.61	.610	.448	.427	.415				
5	12	Indent & Head	200T	139.000	2.020	139.000	1.10	1.099	.488	.458	.440				
2	13	Head Turn	Screw Mach 8 Spdle	102.860	1.263	102.860	6.11	6.110	6.110	6.110	3.175	3.053	3.053	2.999	
5	14	Pierce Flash Hole	5T Horizontal	63.940	3.367	63.940	0.61	.488	.488						
2	15	Pretaper Trim	Rotary	23.630	2.525	23.630	0.61	.610	.448	.427					
5	16	Taper	65T Horizontal	83.400	3.367	83.400	1.83	1.282	1.099						
11	17	Preharden Wash	Multistage Washer	10.000	4.870	10.000	0								
11	18	Harden & Quench	1800° Tube Type	278.000	5.050	278.000	0								
11	19	Temper	800° Belt	79.230	5.050	79.230	0								
3	20	Base Anneal	50 KW Ind	208.500	5.050	208.500	0								
3	21	Mouth Anneal	50 KW Ind	132.050	5.050	132.050	0								
2	22	Final Trim	Multiple Shimmy Trim	61.160	3.367	61.160	0.61	.488	.448						
11	23	Rinse & Dry	Multistage Washer	10.000	4.870	10.000	0								
5	24	Mouth Size	20T	15.290	3.367	15.290	2.44	1.832	1.628						
3	25	Coating Sys.	Lacq, Varn, or Phosph	319.700	5.050	319.700	0								
5	26	4th Draw	150T(j=1)/200T(j=2)	104.250	3.367	139.000	0.98	.794	.733						
2	27	4th Draw Trim	Rotary	23.630	2.020	23.630	0.61	.610	.448	.427	.415				
5	28	5th Draw	200T	---	3.367	139.000	0.98	.794	.733						
2	29	5th Draw Trim	Rotary	---	2.020	23.630	0.61	.610	.448	.427	.415				
5	30	6th Draw	200T	---	3.367	139.000	0.98	.794	.733						
2	31	6th Draw Trim	Rotary	---	2.020	23.630	0.61	.610	.448	.427	.415				

1/ Equipment capacity assumed to be established to process cases requiring cupping and 3 draws (equipment processes each case 4 times at the capacity shown); $N_{i,k}$ equation 10 adjusts effective production rate to provide additional process capacity when more than 3 draws are required.

TABLE 9 ALUMINUM CARTRIDGE CASE (k=8) (FY 75 $)

$N_{i,k}$ Equ	i	Equipment Item: Operation	Equipment Item: Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8 → ∞)
5	1	Blank & Cup	250T Mech Press	$ 228.000	8.67	11.00					
12	2	Anneal	Annealing Oven	90.000	10.33	0					
12	3	Wash, Rinse, & Dry; Lube & Dry	Metalwash Wash Tank/Ranschoff	195.000	10.33	0					
5	4	1st Draw	75T Mech Press	134.200	8.67	0.88					
5	5	2d Draw	75T Mech Press	119.200	8.67	0.88					
13	6	Trim	V&O Trimmer	270.000	8.67	0.55					
5	7	3d Draw	75T Mech Press	119.200	8.67	0.88					
13	8	Trim	V&O Trimmer	251.000	8.67	0.55					
12	9	Anneal	Annealing Oven	90.000	10.33	0					
12	10	Wash, Rinse, & Dry; Lube & Dry	2-stage Horiz Wash/ 2-stage Horiz Wash & Dry	187.000	11.08	0					
5	11	Pocket	175T Horiz Heading Press	318.000	8.67	0.95					
5	12	Head	175T Horiz Heading Press	318.000	8.67	0.95					
5	13	Initial Taper	75T 4-Bar Link Press	119.200	8.67	1.65					
5	14	Final Taper	75T 4-Bar Link Press	119.200	8.67	1.65					
12	15	Heat Treat	Elec Oven & Quench Tank	74.000	20.83	0					
12	16	Age	Aging Oven	70.000	20.83	0					
13	17	Machine Head	8-Spindle Screw Machine	92.200	2.17	5.50	5.50	4.62	4.15		
13	18	Final Trim	Multiple Shimmy Trim	54.800	2.92	0.55	.44	.40			
14	19	Mouth Anneal	Induction Annealer	118.300	10.33	0					
14	20	Anodize	Auto-Anodize	150.000	1.08	0					
13	21	Identification	Marking Machine	5.000	8.67	0					
5	22	4th Draw	75T Mech Press	119.200	8.67	0.88					
5	23	5th Draw	75T Mech Press	119.200	8.67	0.88					
13	24	Trim	V&O Trimmer	251.000	8.67	0.55					
12	25	Anneal	Annealing Oven	90.000	10.33	0					
12	26	Wash, Rinse, & Dry; Lube & Dry	2-stage Horiz Wash/ 2-stage Horiz Wash & Dry	187.000	11.08	0					
5	27	6th Draw	75T Mech Press	119.200	8.67	0.88					

SECTION III

MODEL FORMAT

A. Inputs

The inputs required to exercise the model are summarized below, and are described in additional detail in paragraph IIIB.

1. Peak annual production quantity, in millions, of each component including link and metal ammunition box, the latter expressed as the annual quantity of complete rounds to be packed.

The estimator should carefully determine the annual production quantity requirements (Q values defined in paragraph IIIB) for each component and LAP. These are the annual production quantities for which IPE and/or initial tooling is either not in existence or, if in existence, is neither partially nor wholly available. Since existing capacity may be available during the production time frame to partially or wholly meet the total program requirements of given components or LAP, the Q values may or may not be those established to meet the total program requirements. Therefore, the Q values are established to meet a production "shortfall" or deficiency, and, since they are inputs provided by the estimator, may well be determined by means of a separate analysis or model. With the exception of fuzes, for which initial tooling is included in IPE cost, and for which the production quantity requirement is symbolized as Q_f, separate production quantity inputs symbolized as QE_k and QT_k are required for IPE and initial tooling, respectively. QE_k and Q_f are established to meet the IPE deficiency discussed above. For example, if the maximum annual requirement for a component or LAP is ten million, and existing capacity will be available to produce four million, additional IPE will be required to produce the deficiency of six million per year, and QE_k is input as that value. However, even if IPE is partially or wholly available, initial tooling will probably be required to meet the total program requirements since the ammunition being estimated is likely to be of a different size and/or design configuration than that for which the production line was established. Therefore, QT_k will generally be input as the total program annual requirement--ten million in the above example. When sufficient capacity is found to be available to meet the total program requirements for a given component or LAP, the applicable Q value is input as zero, and no IPE or initial tooling is estimated. On the other hand, when a production base is neither in existence nor available, certain relationships exist among the Q values, as follows:

a. QE_4 through QE_7 or QE_8 (link, box, LAP, and cartridge case) each equals the sum of QE_1, QE_2, and QE_3 (sum of projectile quantities).

b. The relationship of 1, above, exists for the same subscripted values of QT_k.

c. Q_f (fuze) equals Q_1 (HEIT projectile).

The model assumes that TME is required whether or not IPE is available.

2. Number of production shifts assumed for each component (1,2, or 3).

3. Projectile diameter, in millimeters.

4. Projectile length, in inches.

5. Cartridge case length, in inches.

6. Number of rounds per metal ammunition box known or assumed for the estimate.

This input acts to adjust the number of boxes required, for the quantity of ammunition being estimated, from a number based on 100 linked rounds packed in a container similar to the M548 box. The input is a function of a reasonable weight assumed for manual handling. Since complete round weight is not likely to be known for early estimates, the number of rounds can be estimated by comparison with the method of packing of existing automatic cannon ammunition. For example, the following are the approximate weights, in pounds, of the M246 20mm HEIT cartridge:

	Net(less packing and container)	Packed Out
100 rounds linked	69	91
200 rounds bulk packed	114	141

If an existing, standard box is not suitable, the estimator should ascertain that the cubic-inch volume of the container being estimated does not significantly exceed the volume of the M548 box, to avoid exceeding the equipment requirements and capacities in Table 6. The inside dimensions of the M548 box are 17 1/4 inches long, 7 7/16 inches wide, and 13 63/64 inches high. A moderate increase - 15% to 20% - in these dimensions would not be expected to significantly impact the results of the estimate.

B. Mathematical Notation

The notation used in the cost equations is identical to that used in the base (reference 1) model except for redefinition of the Q values; use of a different symbol for number of shifts; and the addition of an f (fuze) subscript, N_d (number of draws) symbol, component dimension symbols, and symbols denoting constants. The notation applies to the symbolic equations shown in paragraph IIIC1. Solution of the model can also be tracked using the word equations of paragraph IIIC1, and the sequences of solution shown in Table 10.

The notation is uniform in applicability to each matrix, and is defined below. Except for S_k, Z, and production-rate (Q) values QE_k, QT_k, and Q_f, which are inputs provided by the estimator, the symbols represent either data base (matrix) values or values yielded by the cost equations.

Subscripts

f Identifies fuze (not a matrix subscript).

i Matrix row; it specifies a specific item of equipment and associated initial tooling.

j Matrix column; it refers either to equipment unit cost, annual equipment capacity per shift, or average unit initial tooling cost.

k The specific matrix; e.g., when k = 1, the HEIT projectile matrix, Table 2, is specified.

Symbols

D Projectile diameter of the ammunition family for which IPF is being estimated. Expressed in mm, this value ranges from 20mm through 40mm.

L_c Cartridge case length, in inches.

L_p Projectile length, in inches.

S_k Number of working shifts assumed in the estimate for the ammunition component identified by the value of k, where a shift is eight hours per day, five days per week (1-8-5). When one shift is assumed, S_k is given the value of 1; similarly, $S_k = 2$ and $S_k = 3$ for two shifts and three shifts, respectively. An additional adjustment to the value of S_k can be made if the estimate is to be based on a working shift other than eight hours per day and/or five days per week. For example, if the desired shift is 2-8-6, $S_k = 2(6/5) = 2.4$. Or, for a 2-10-5 shift, $S_k = 2(10/8) = 2.5$.

S_f Same as S_k, but applicable to fuzes only.

QE_k Peak annual production quantity of the ammunition component specified by the value of k, in millions, for which IPE is required; this value is set equal to zero if no IPE is required.

Q_f Peak annual fuze production quantity, in millions; this value is set equal to zero if no fuze IPF is required.

QT_k Peak annual production quantity of the ammunition component specified by the value of k, in millions, for which <u>initial tooling</u> is required; this value is set equal to zero if no initial tooling is required.

$X_{i,j,k}$ Numerical value (equipment or unit initial tooling cost, or equipment capacity) located at the intersection of row i and column j of matrix k; e.g., $X_{3,2,1}$ provides the value of 1.700 million rounds as the annual capacity per shift for the centerless grinder required to produce the HEIT projectile.

$N_{i,k}$ Required quantity of the equipment item specified by row i of matrix k. In the solution of the model, this factor represents either the quantity of each equipment item or the number of sets of initial tooling associated with each equipment item. For example, $N_{3,1}$ represents the number of centerless grinders, each grinder having an annual capacity of $S_1X_{3,2,1}$ rounds, required to produce QE_1 or QT_1 HEIT projectiles. This value is rounded to the next larger integer (number of whole equipment items). For example, if the cost equation for $N_{i,k}$ yields a value of 2.005, then $N_{i,k}$ is rounded to 3.

N_d Number of press drawing operations required in the manufacture of a cartridge case; assumes a value from 3 to 6 depending on case length.

N_f Number of fuze lines required to meet annual fuze production requirements, rounded to the next larger integer as defined for $N_{i,k}$, above.

$Y_{i,k}$ Total cost in thousands of dollars of the equipment item specified by row i of matrix k, or its associated initial tooling; it is a function of $N_{i,k}$ and $X_{i,j,k}$.

Y_k Total cost in thousands of dollars of the equipment needed to meet production requirements of the ammunition component specified by the value of k. It represents the summation of previously-calculated values of $Y_{i,k}$. When applied to IPE, it includes the selective allowances for transportation, installation, layaway, and miscellaneous material handling equipment.

Y_f Total cost of the fuze line(s) required to meet fuze production requirements, including layaway cost.

Z The number of rounds per metal ammunition box known or assumed for the estimate; this input value may or may not be equal to the constant C_3.

T_k Total cost in thousands of dollars of the TME required for the component specified by the value of k; it is independent of the quantity specified by Q_k.

T_f Total cost in thousands of dollars of the TME required for fuzes; it is independent of the quantity specified by Q_f.

<u>Constants</u>

C_1 1.10, a 10 percent allowance for layaway costs. The allowance consists of 6 percent for preservation and 4 percent for crating, handling, and transportation. If the layaway is on site, only the 6 percent factor is applicable; however, the 10 percent factor is used in the model to yield a conservative estimate, on the assumption that on-site layaway versus plant clearance is not known at the time the estimate is being made.

C_2 1.05, a 5 percent allowance for transportation and installation costs.

C_3 100 rounds per ammunition box, the quantity on which the box matrix, Table 6, is based (see note, bottom of Table 6).

C_4 1.10, a 10 percent allowance for miscellaneous material handling equipment costs.

C_5 1.2, a constant annual production capacity per fuze line per shift, expressed in millions.

C_6 2, a factor which provides for doubling of the initial tooling matrix value for steel cartridge cases (k=7), when the total case length is greater than 3.5 inches, <u>and</u> the projectile diameter is greater than 20mm and equal to or less than 40mm (see paragraph IIIC1). This factor is based on the engineering judgment of LCAAP personnel, and is established to account for the higher cost of the heavier press tooling required.

C_7 2,000, the average unit cost per fuze line in thousands of dollars, including transportation and installation cost but excluding layaway cost.

C. Cost Equations

1. Dimensional Adjustments

As indicated in paragraphs IIA2, IIA4, and IIB2, the approach to modeling dimensional adjustments was based on judgmental analysis of the equipment and process by equipment item, was of necessity confined to capacity impacts in terms of overall component dimensions that are known or assumed at the time of the estimate, and represents an approach to IPF modeling which is designed to move estimated costs in the proper direction and which can be refined over time.

Dimensional adjustments are made to the base (reference 1) model equations for $N_{i,k}$ (equipment quantity). The resulting, modified equations are listed in paragraph IIIC2. The adjustments take three forms, discussed by equation number.

a. Adjustment to equipment quantity based on relevant component dimensions.

The equations show that this type of adjustment is applied as the ratio or percentage of the ratio of component dimension(s) assumed to affect process cycle time to the equivalent dimension(s) represented by the data base (Bushmaster 25mm or GAU-8 30mm). An example is shown for equation 1, below. The adjustments by equation are:

(1) Equation 1: Machining time is affected by both projectile diameter and length; the impact is estimated at 40 percent of total cycle time. The adjustment is also based on comparison with the M56A3 20mm HEI projectile, and is used for similar operations on all three projectiles in the model. An example of the adjustment is the Oerlikon 35mm round, having a projectile length of 7.4 inches, with the adjustment applied to the capacity of the automatic screw machine (i = 1) of Table 2. The product of projectile diameter and length is DLp = 35 (7.4) = 259. This value is divided by the equivalent value for the projectile on which the equipment item capacity is based, i.e., 25 (4.6) = 115. The result states, for purposes of adjusting for this particular production operation, that the Oerlikon round is 2.25 times "bigger" than the 25mm round on which Table 2 is based. However, as shown by the equation, the adjustment is made only to the difference, 2.25 minus 1, or 1.25. The resulting adjustment factor of 1.50 reduces the equipment capacity per shift from 0.383 million to 0.255 million (or, increases the effective annual quantity input by an additional 50 percent). If DLp is 115, the adjustment becomes unity, and no adjustment is made; and, if DLp is less than 115, the adjustment is negative, acting to increase the equipment capacity or reduce the effective annual quantity. The foregoing is typical of all equations for equipment item quantity where an adjustment is made.

(2) Equation 2: Machining time is primarily affected by projectile diameter; the impact is estimated at 40 percent of total cycle time. The adjustment is also based on comparison with the M56A3 projectile, and is used for similar operations on all three projectiles in the model as well as diameter-related machining on the steel cartridge case.

(3) Equation 3: Processing time is primarily affected by projectile diameter (indirectly when applied to in-process steps in steel cartridge case manufacture); in certain applications, the adjustment assumes vertical part orientation with processing at a fixed, optimum speed.

(4) Equation 4: Processing time is minimally affected by component dimensions; the adjustment is estimated at 10 percent to account for handling bulk (weight) only.

(5) Equation 5: No adjustment. In the case of link manufacture, no pattern of dimensional changes due to cartridge case dimensions was found; link design is predominently driven by weapon characteristics.

(6) Equation 6: Unchanged from reference 1 model (applies to ammunition box only).

(7) Equation 7: Processing time is assumed to be primarily affected by projectile length. Assumes automatic charging independent of caliber. The adjustment is also based on comparison with the M56A3 HEI projectile description of manufacture.

(8) Equation 8: Processing time is assumed to be affected by cartridge case length; impact is estimated at 30 percent of total cycle time. Assumes automatic processing independent of caliber.

(9) Equation 9: Processing time is assumed to be affected by projectile diameter; impact is estimated at 20 percent of total cycle time. Assumes automatic processing independent of cartridge length.

(10) Equation 10: Bulk processing is assumed, with diameter and length utilized as a measure of relative cartridge case bulk. The N_d (number of draws) adjustment accounts for additions to the "effective" quantity of cartridge cases resulting from additional requirements for the affected processes as the number of press drawing operations increases (see paragraph b, below, and Note 1, Table 8).

(11) Equation 11: Same as equation 10, excluding the N_d adjustment.

(12) Equation 12: Same as equation 11 except based on the GAU-8 diameter and cartridge case length.

(13) Equation 13: Machining is primarily affected by diameter; impact is estimated at 40 percent of total cycle time.

(14) Equation 14: Processing assumes vertical orientation and automatic processing independent of cartridge case length.

b. Adjustment to the number of press drawing and associated processes over ranges of cartridge case length.

Investigation by the HQ, ARMCOM Plant Operations Directorate indicates that, for either brass or steel, drawing can be estimated to double the previously-drawn length. The model then assumes a maximum case length of 3.5 inches as requiring three draws (same assumption as the reference 1 model), and establishes doubled ranges of case length above 3.5 inches within each of which an additional draw, trim, and related processing as required, is added. This results in a general-purpose model only, which accounts for increased processing for greater case lengths based on a dimension which is known or can be assumed for early estimates. For this reason, the same general model is applied to aluminum cases. It is recognized that the actual number of draws required for a specific cartridge case will be a function of material, case length, diameter, wall thickness, and similar discrete design detail.

c. Adjustments to initial tooling cost based on caliber.

This adjustment accounts for the generally varying size of initial tooling with varying sizes of the components being manufactured. Tooling cost is adjusted by 10 percent for each five millimeters of caliber, based on the approach taken by Lake City Army Ammunition Plant in developing the 25mm base tooling data used in the reference 1 study.

2. <u>Equation Forms and Sequences of Solution</u>

The cost equations which are solved in the execution of the modified model are listed below in both symbolic and word form. The model contains 50 distinct equations, of which 33 are common to the solution of either a steel-case or aluminum-case family of ammunition. A full solution utilizes 42 equations for a steel-case family, and 41 equations for an aluminum case family. The initial equations, which solve for the quantity of equipment items required to meet the production-rate input, are identified by equipment item in Tables 2 through 9. The sequences of solution following the initial equations are shown by component in Table 10. In addition, the following should be noted:

a. Units of measure for inputs are as defined in paragraph IIIA.

b. Values of j (matrix column) are specified for all equations in which a value of j is required.

c. Equations which are iteratively solved over a range of values of i are solved for all values of i within each matrix except as otherwise noted.

d. Equations for $N_{i,k}$ (equipment item quantity) are identified as 1a, 2a, ..., 14a for IPE, and 1b, 2b, ..., 14b for initial tooling. The equations are identical except for the variable Q.

e. Alternative (conditional) choices of equation for $Y_{i,k}$ for steel cartridge cases are provided. These are based on a variation in both the number of drawing operations and the press tonnages required for the blanking and drawing operations, depending on the length and diameter of the cartridge case being estimated. The former variation is accounted for by the addition of draw and trim operations in Table 8; and the latter is accounted for by variations in affected press tonnages, and the addition of both a second column of equipment unit costs (j=3) to Table 8 and doubling of the average unit tooling cost (equation 29) to accommodate the higher tonnages. These variations are taken directly from the reference 1 model, but with additional draw-trim operations to accommodate a wider range of case lengths. Only variations in drawing, trimming, and associated material-treatment processes driven by case length are included in the aluminum case model, and these are handled by varying the number of equipment items (values of i), not with conditional equations.

Equation Number	Equation
	IPE
1a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.4 \left(\frac{DL_p}{115} -1 \right) \right]$, where j = 2
2a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.4 \left(\frac{D}{25} -1 \right) \right]$, where j = 2
3a	$N_{i,k} = \frac{D\ QE_k}{25\ S_k X_{i,j,k}}$, where j = 2
4a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.1 \left(\frac{DL_p}{115} -1 \right) \right]$, where j = 2
5a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}}$, where j = 2
6a	$N_{i,k} = \frac{C_3\ QE_k}{Z\ S_k X_{i,j,k}}$, where j = 2
7a	$N_{i,k} = \frac{L_p\ QE_k}{4.6\ S_k X_{i,j,k}}$, where j = 2
8a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.3 \left(\frac{L_c}{5.4} -1 \right) \right]$, where j = 2
9a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.2 \left(\frac{D}{25} -1 \right) \right]$, where j = 2

Equation Number	Equation
10a	$N_{i,k} = \dfrac{DL_c QE_k}{135\ S_k X_{i,j,k}} \left[\dfrac{4+(N_d-3)}{4}\right],$ where $j = 2$, $N_d = 3$ for $L_c \leq 3.5$ in., $N_d = 4$ for 3.5 in.$< L_c \leq 7$ in., $N_d = 5$ for 7 in.$< L_c \leq 14$ in., and $N_d = 6$ for $L_c > 14$ in.
11a	$N_{i,k} = \dfrac{DL_c QE_k}{135\ S_k X_{i,j,k}}$, where $j = 2$
12a	$N_{i,k} = \dfrac{DL_c QE_k}{204.3\ S_k X_{i,j,k}}$, where $j = 2$
13a	$N_{i,k} = \dfrac{QE_k}{S_k X_{i,j,k}} \left[1+0.4\left(\dfrac{D}{30}-1\right)\right]$, where $j = 2$
14a	$N_{i,k} = \dfrac{D\ QE_k}{30\ S_k X_{i,j,k}}$, where $j = 2$
15	$N_f = \dfrac{QE_k}{C_5 S_f}$
16	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = 1$
17	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = 1$, and $i = 1, 2, \ldots, 25$
18	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = 1$, and $i = 1, 2, \ldots, 27$
19	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = 3$, $i = 1, 2, \ldots, n$, $n = 27$ for 3.5 in.$< L_c \leq 7$ in., $n = 29$ for 7 in.$< L_c \leq 14$ in., and $n = 31$ for $L_c > 14$ in.

Equation Number	Equation
20	$Y_{i,k}X_{i,j,k}$, where $j = 1$, $i = 1, 2, \ldots, n$, $n = 21$ for $L_c \leq 3.5$ in., $n = 22$ for $3.5 \text{ in.} < L_c \leq 7$ in., $n = 26$ for $7 \text{ in.} < L_c \leq 14$ in., $n = 27$ for $L_c > 14$ in.
21	$Y_k = C_1C_2\sum Y_{i,k}$
22	$Y_k = C_1C_2C_4\sum Y_{i,k}$
23	$Y_f = C_7N_fC_1$

Initial Tooling

1b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}\left[1+0.4\left(\dfrac{DL_p}{115} -1\right)\right]$, where $j = 2$
2b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}\left[1+0.4\left(\dfrac{D}{25} -1\right)\right]$, where $j = 2$
3b	$N_{i,k} = \dfrac{D\ QT_k}{25\ S_kX_{i,j,k}}$, where $j = 2$
4b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}\left[1+0.1\left(\dfrac{DL_p}{115} -1\right)\right]$, where $j = 2$
5b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}$, where $j = 2$
6b	$N_{i,k} = \dfrac{C_3QT_k}{Z\ S_kX_{i,j,k}}$, where $j = 2$

Equation Number	Equation
7b	$N_{i,k} = \dfrac{L_p QT_k}{4.6\ S_k X_{i,j,k}}$, where $j = 2$
8b	$N_{i,k} = \dfrac{QT_k}{S_k X_{i,j,k}} \left[1+0.3\left(\dfrac{L_c}{5.4} -1\right)\right]$, where $j = 2$
9b	$N_{i,k} = \dfrac{QT_k}{S_k X_{i,j,k}} \left[1+0.2\left(\dfrac{D}{25} -1\right)\right]$, where $j = 2$
10b	$N_{i,k} = \dfrac{DL_c QT_k}{135\ S_k X_{i,j,k}} \left[\dfrac{4+(N_d-3)}{4}\right]$, where $j = 2$, $N_d = 3$ for $L_c \leq 3.5$ in.; $N_d = 4$ for 3.5 in. $< L_c \leq 7$ in.; $N_d = 5$ for 7 in. $< L_c \leq 14$ in.; $N_d = 6$ for $L_c > 14$ in.
11b	$N_{i,k} = \dfrac{DL_c QT_k}{135\ S_k X_{i,j,k}}$, where $j = 2$
12b	$N_{i,k} = \dfrac{DL_c QT_k}{204.3\ S_k X_{i,j,k}}$, where $j = 2$
13b	$N_{i,k} = \dfrac{QT_k}{S_k X_{i,j,k}} \left[1+0.4\left(\dfrac{D}{30} -1\right)\right]$, where $j = 2$
14b	$N_{i,k} = \dfrac{D\ QT_k}{30\ S_k X_{i,j,k}}$, where $j = 2$
24	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = N_{i,k} + 2$
25	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = N_{i,k} + 3$, $i = 1, 2, \ldots, n$, $n = 25$ for $L_c \leq 3.5$ in.; $n = 27$ for 3.5 in. $< L_c \leq 7$ in.; $n = 29$ for 7 in. $< L_c \leq 14$ in.; $n = 31$ for $L_c > 14$ in.

Equation Number	Equation
26	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = N_{i,k} + 2$, $i = 1, 2, \ldots, n$, $n = 21$ for $L_c \leq 3.5$ in. $n = 22$ for $3.5 \text{ in.} < L_c \leq 7$ in. $n = 26$ for $7 \text{ in.} < L_c \leq 14$ in. $n = 27$ for $L_c > 14$ in.
27	$Y_k = \sum Y_{i,k}$
28	$Y_k = \left[(1.02)^{D-25} \right] \sum Y_{i,k}$
29	$Y_k = C_6 \left[(1.02)^{D-25} \right] \sum Y_{i,k}$
30	$T_k = 26.6$, where $k = 1$ and 2
31	$T_k = 25.0$, where $k = 3$
32	$T_k = 29.9$, where $k = 4$
33	$T_k = 11.7$, where $k = 5$
34	$T_k = 42.7$, where $k = 6$
35	$T_k = 60.5$, where $k = 7$ and 8
36	$T_f = 198.2$ for fuzes

Equation Number	Equip Capacity or Cost-Table Column(j) Number	Equation
		IPE
1a	2	$\text{Equip Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts} \times \text{Cap/Shift/Yr}} \left[1+0.4\left(\frac{\text{Dia} \times \text{Proj Length}}{115} - 1\right)\right]$
2a	2	$\text{Equip Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts} \times \text{Cap/Shift/Yr}} \left[1+0.4\left(\frac{\text{Dia}}{25} - 1\right)\right]$
3a	2	$\text{Equip Item Qty} = \frac{\text{Dia} \times \text{Qty/Yr}}{25 \times \text{No.Shifts} \times \text{Cap/Shift/Yr}}$
4a	2	$\text{Equip Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts} \times \text{Cap/Shift/Yr}} \left[1+0.1\left(\frac{\text{Dia} \times \text{Proj Length}}{115} - 1\right)\right]$
5a	2	$\text{Equip Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts} \times \text{Cap/Shift/Yr}}$
6a	2	$\text{Equip Item Qty} = \frac{100 \text{ Rnds/Box} \times \text{Qty/Yr}}{\text{No.Rnds/Box} \times \text{No.Shifts} \times \text{Cap/Shift/Yr}}$
7a	2	$\text{Equip Item Qty} = \frac{\text{Proj Length} \times \text{Qty/Yr}}{4.6 \times \text{No.Shifts} \times \text{Cap/Shift/Yr}}$
8a	2	$\text{Equip Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts} \times \text{Cap/Shift/Yr}} \left[1+0.3\left(\frac{\text{Case Length}}{5.4} - 1\right)\right]$
9a	2	$\text{Equip Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts} \times \text{Cap/Shift/Yr}} \left[1+0.2\left(\frac{\text{Dia}}{25} - 1\right)\right]$
10a	2	$\text{Equip Item Qty} = \frac{\text{Dia} \times \text{Case Length} \times \text{Qty/Yr}}{135 \times \text{No.Shifts} \times \text{Cap/Shift/Yr}} \left[\frac{4 + (\text{No.Draws} - 3)}{4}\right]$, where number of draws is 3 for case lengths less than or equal to 3.5 inches, 4 for case lengths greater than 3.5 inches and less than or equal to 7 inches, 5 for case lengths greater than 7 inches and less than or equal to 14 inches, and 6 for case lengths greater than 14 inches.

Equation Number	Equip Capacity or Cost-Table Column(j) Number	Equation
11a	2	Equip Item Qty = $\frac{\text{Dia x Case Length x Qty/Yr}}{\text{135 x No.Shifts x Cap/Shift/Yr}}$
12a	2	Equip Item Qty = $\frac{\text{Dia x Case Length x Qty/Yr}}{\text{204.3 x No.Shift x Cap/Shift/Yr}}$
13a	2	Equip Item Qty = $\frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}} \left[1+0.4 \; \frac{\text{Dia}}{30} \; -1\right]$
14a	2	Equip Item Qty = $\frac{\text{Dia x Qty/Yr}}{\text{30 x No.Shifts x Cap/Shift/Yr}}$
15	---	No. Fuze Lines = $\frac{\text{Qty/Yr}}{1.2\ \overline{\text{M}}\text{/Line/Shift x No.Shifts}}$
16	1	Equip Item Cost = Equip Item Qty x Equip Item Unit Cost
17	1	Equip Item Cost = Equip Item Qty x Equip Item Unit Cost, for Equip Items i = 1 - 25, incl.
18.	1	Equip Item Cost = Equip Item Qty x Equip Item Unit Cost, for Equipment Items i = 1 - 27, incl.
19	3	Equip Item Cost = Equip Item Qty x Equip Item Unit Cost, where equipment items are i = 1 - 27, incl. for case lengths greater than 3.5 inches and less than or equal to 7 inches; i = 1 - 29, incl. for case lengths greater than 7 inches and less than or equal to 14 inches; and i = 1 - 31, incl. for case lengths greater than 14 inches.
20	1	Equip Item Cost = Equip Item Qty x Equip Item Unit Cost, where equipment items are i = 1 - 21, incl. for case lengths less than or equal to 3.5 inches; i = 1 - 22, incl. for case lenghts greater than 3.5 inches and less than or equal to 7 inches; i = 1 - 26, incl. for case lengths greater than 7 inches and less than or equal to 14 inches; and i = 1 - 27, incl. for case lengths greater than 14 inches.

Equation Number	Equip Capacity or Cost-Table Column(j) Number	Equation
21	---	Total Equip Cost = 1.10 Layaway Allowance x 1.05 Transp & Inst Allowance x $\sum$ Equip Item Cost
22	---	Total Equip Cost = 1.10 Layaway Allowance x 1.05 Transp & Inst Allowance x 1.10 Misc Matl Hand Equip Allowance x $\sum$ Equip Item Cost
23	---	Total Fuze Line Cost = 2,000/Fuze Line x No. Fuze Lines x 1.10 Layaway Allowance
		<u>Initial Tooling</u>
1b	2	Tooling Item Qty = $\frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}\left[1+0.4\left(\frac{\text{Dia x Proj Length}}{115}-1\right)\right]$
2b	2	Tooling Item Qty = $\frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}\left[1+0.4\left(\frac{\text{Dia}}{25}-1\right)\right]$
3b	2	Tooling Item Qty = $\frac{\text{Dia x Qty/Yr}}{\text{25 x No.Shifts x Cap/Shift/Yr}}$
4b	2	Tooling Item Qty = $\frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}\left[1+0.1\left(\frac{\text{Dia x Proj Length}}{115}-1\right)\right]$
5b	2	Tooling Item Qty = $\frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}$
6b	2	Tooling Item Qty = $\frac{\text{100 Rnds/Box x Qty/Yr}}{\text{No.Rnds/Box x No.Shifts x Cap/Shift/Yr}}$
7b	2	Tooling Item Qty = $\frac{\text{Proj Length x Qty/Yr}}{\text{4.6 x No.Shifts x Cap/Shift/Yr}}$

Equation Number	Equip Capacity or Cost-Table Column(j)Number	Equation
8b	2	$\text{Tooling Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}\left[1+0.3\left(\frac{\text{Case Length}}{5.4}-1\right)\right]$
9b	2	$\text{Tooling Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}\left[1+0.2\left(\frac{\text{Dia}}{25}-1\right)\right]$
10b	2	$\text{Tooling Item Qty} = \frac{\text{Dia x Case Length x Qty/Yr}}{\text{135 x No.Shifts x Cap/Shift/Yr}}\left[\frac{4+(\text{No.Draws}-3)}{4}\right]$, where number of draws is 3 for case lengths less than or equal to 3.5 inches, 4 for case lengths greater than 3.5 inches and less than or equal to 7 inches, 5 for case lengths greater than 7 inches and less than or equal to 14 inches, and 6 for case lengths greater than 14 inches.
11b	2	$\text{Tooling Item Qty} = \frac{\text{Dia x Case Length x Qty/Yr}}{\text{135 x No.Shifts x Cap/Shift/Yr}}$
12b	2	$\text{Tooling Item Qty} = \frac{\text{Dia x Case Length x Qty/Yr}}{\text{204.3 x No.Shifts x Cap/Shift/Yr}}$
13b	2	$\text{Tooling Item Qty} = \frac{\text{Qty/Yr}}{\text{No.Shifts x Cap/Shift/Yr}}\left[1+0.4\left(\frac{\text{Dia}}{30}-1\right)\right]$
14b	2	$\text{Tooling Item Qty} = \frac{\text{Dia x Qty/Yr}}{\text{30 x No.Shifts x Cap/Shift/Yr}}$
24	Qty + 2	Tooling Item Cost = Tooling Item Qty x Tooling Item Unit Cost

Equation Number	Equip Capacity or Cost-Table Column(j) Number	Equation
25	Qty + 3	Tooling Item Cost = Tooling Item Qty x Tooling Item Unit Cost, where tooling items are i = 1 - 25, incl. for case lengths less than or equal to 3.5 inches; i = 1 - 27, incl. for case lengths greater than 3.5 inches and less than or equal to 7 inches; i = 1 - 29, incl. for case lengths greater than 7 inches and less than or equal to 14 inches; and i = 1 - 31, incl. for case lengths greater than 14 inches.
26	Qty + 2	Tooling Item Cost = Tooling Item Qty x Tooling Item Unit Cost, where tooling items are i = 1 - 21, incl. for case lengths less than or equal to 3.5 inches; i = 1 - 22, incl. for case lengths greater than 3.5 inches and less than or equal to 7 inches; i = 1 - 26, incl. for case lengths greater than 7 inches and less than or equal to 14 inches; and i = 1 - 27, incl. for case lengths greater than 14 inches.
27	---	$\text{Total Tooling Cost} = \sum \text{Tooling Item Cost}$
28	---	$\text{Total Tooling Cost} = \left[(1.02)^{\text{Dia}-25}\right] \sum \text{Tooling Item Cost}$
29	---	$\text{Total Tooling Cost} = 2\left[(1.02)^{\text{Dia}-25}\right] \sum \text{Tooling Item Cost}$

Table 10. Cost Equation Sequences of Solution - N_f, $Y_{i,k}$, Y_k, and Y_f 1/

Component	Equation Numbers
1. Projectiles (k=1,2,3)	
a. IPE	16, 21
b. Initial Tooling	24, 28
c. TME	
(1) k=1,2	30
(2) k=3	31
2. Link (k=4)	
a. IPE	16, 21
b. Initial Tooling	24, 28
c. TME	32
3. Box (k=5)	
a. IPE	16, 21
b. Initial Tooling	24, 27
c. TME	33
4. LAP (k=6)	
a. IPE	16, 22
b. Initial Tooling	24, 28
c. TME	34
5. Steel Cartridge Case (k=7)	
a. IPE	
(1) $L \leq 3.5$ in., $D \leq 40$mm	17, 21
(2) $L > 3.5$ in., $D = 20$mm	18, 21
(3) $L > 3.5$ in., $20\text{mm} < D \leq 40$mm	19, 21
b. Initial Tooling	
(1) $L_c \leq 3.5$ in., $D \leq 40$mm	25, 28
(2) $L_c > 3.5$ in., $D = 20$mm	25, 28
(3) $L_c > 3.5$ in., $20\text{mm} < D \leq 40$mm	25, 29
c. TME	35
6. Aluminum Cartridge Case (k=8)	
a. IPE	20, 21
b. Initial Tooling	26, 28
c. TME	35
7. Fuze	
a. IPE	15, 23
b. Initial Tooling	NA
c. TME	36

1/ Equations for $N_{i,k}$ are listed in Tables 2 - 9, incl.

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13. ABSTRACT

A model to provide cost estimates of initial production facilities (IPF) for a 20mm through 40mm steel-case or aluminum-case family of conventional automatic cannon ammunition is presented in this report. The model is intended to facilitate the preparation of independent estimates in support of decision making early in the acquisition phase. It represents a modified version of previous models over the same size range developed by HQ, ARMCOM, Cost Analysis Division, in that different costs among alternative rounds of different calibers and/or component dimensions are generated. The differentiating or adjusting process is based on the premise that production equipment capacities are partially or wholly dependent on the magnitude of certain component dimensions that are known or can be assumed in early estimates.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ammunition						
Cost						
Nonrecurring Investment						
Initial Production Facilities						
Cost Estimating						
Cost Model						
Estimating						
Ammunition Estimating						